DOCUMENT RESUME

ED 056 534 EM 009 396

TITLE	Project Solo; Newsletter Number Fifteen.
INSTITUTION	Pittsburgh Univ., Pa. Dept. of Computer Science.
SPONS AGENCY	National Science Foundation, Washington, D.C.
PUB DATE	6 Apr 71
NOTE	21p.; See also ED 053 566
EDRS PRICE	MF-$0.65 HC-$3.29
DESCRIPTORS	Botany; *Computer Graphics; *Computer Programs; *Computer Science Education; Mathematics Instruction; Programing; *Secondary School Mathematics; Secondary School Students; *Student Developed Materials
IDENTIFIERS	*Project Solo

ABSTRACT

Several plotter programs written by 11th and 12th grade mathematics students are presented, along with two examples illustrating how a student can contribute to non-computer courses using knowledge gained from Project Solo. A curriculum module called "Enumeration" is presented which illustrates a computer-oriented approach to a typical topic in mathematics. (JY)

PROJECT SOLO

AN EXPERIMENT IN REGIONAL COMPUTING
FOR SECONDARY SCHOOL SYSTEMS

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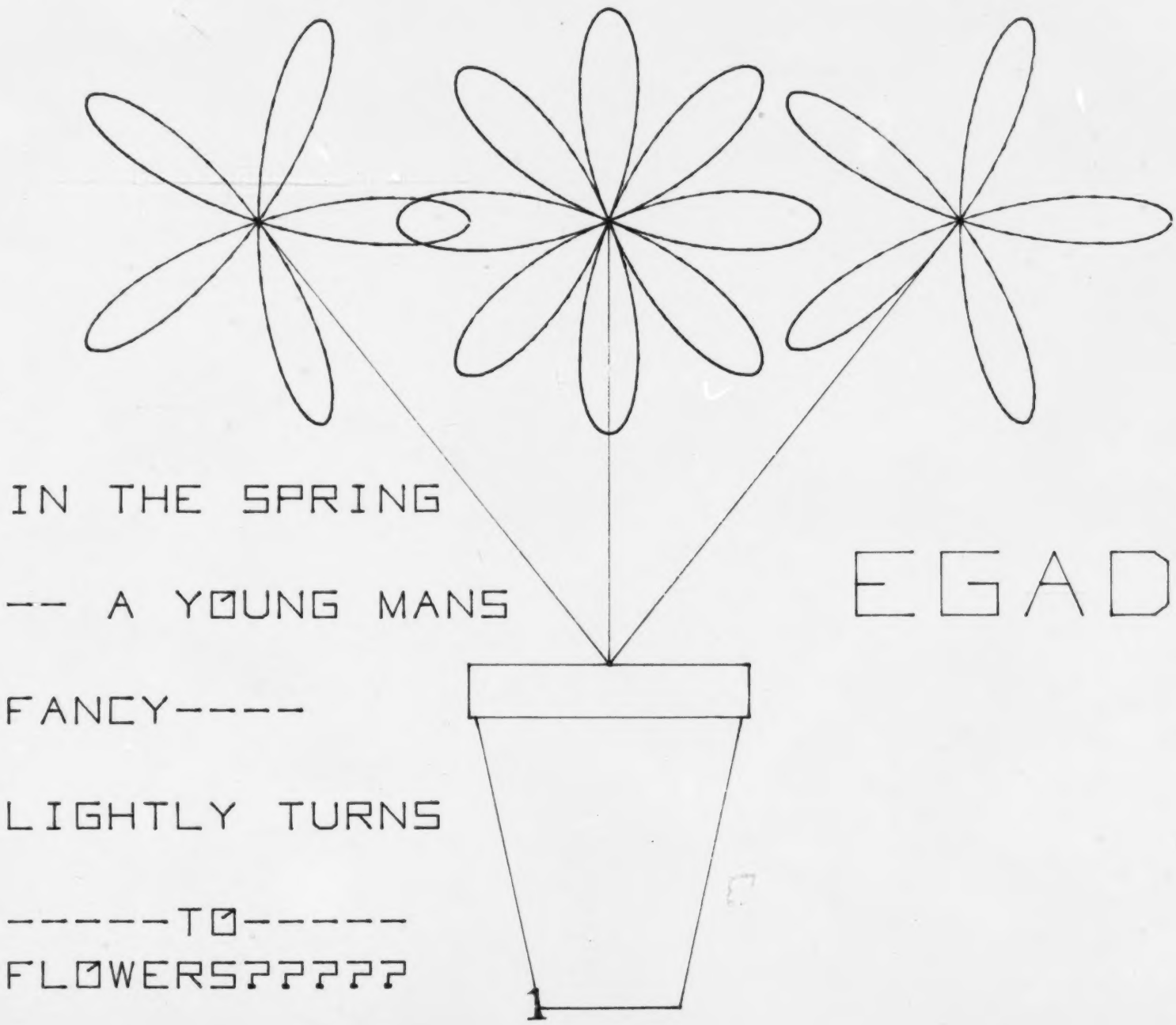
University of Pittsburgh • Department of Computer Science • Pittsburgh, Pennsylvania 15213

Newsletter No. 15 April 6, 1971

ED056534

Spring Fever

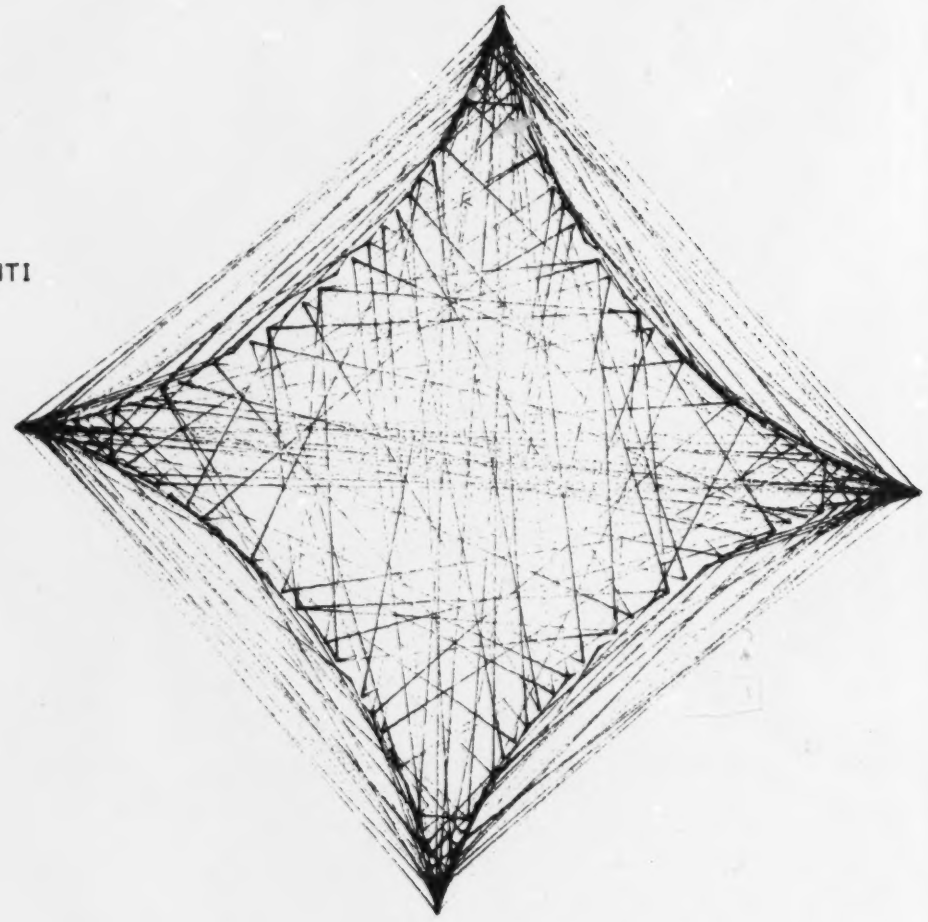
Although newsletter writers tend to lose ambition around this time of year, our computers and plotters are going full steam ahead under the direction of students who seem to be immune to the soporific blandishments of spring zephyrs. We herewith offer a pleasant potpourri of precocious plotter programs perpetrated and produced by 11th and 12th grade mathematics students (who obviously have a flair for the artistic as well). The first example (below) is by Isabelle Wilkens.

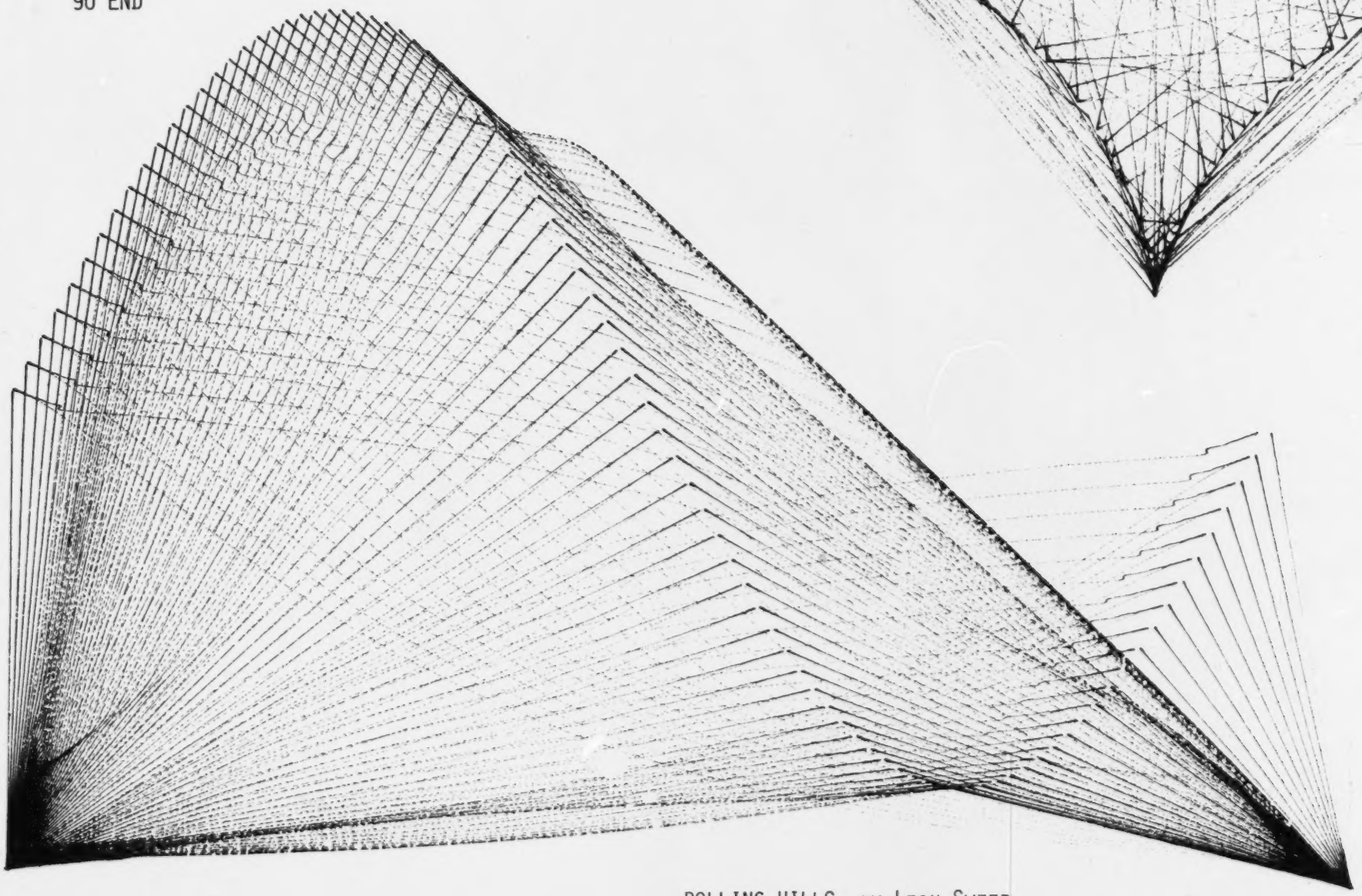


EM 009 396

```
5 FOR A=0 TO PI/2 BY PI/6
10 PR. "PLTL"
20 FOR T=0 TO 2*PI BY PI/32
25 A=T+A
30 X=(COS(A))↑3*3000
40 Y=(SIN(A))↑3*3000
50 PR. INT(X*.755)+5000:INT(Y)+5000
60 NEXT T
70 PR. "PLTT"
75 NEXT A
80 PR. "PLTT"
90 END
```

WORDS & MUSIC BY M.J.VALENTI





ROLLING HILLS BY LEON SWEER

```
TYPE YOUR NICKNAME---THIS PROGRAM WILL 'SIN' IT FOR YOU
?PROJECT SOLO                    PROJECT SOLO
                                       PROJECT SOLO
                                            PROJECT SOLO
                                                 PROJECT SOLO
                                                      PROJECT SOLO
                                                          PROJECT SOLO
                                                           PROJECT SOLO
                                                           PROJECT SOLO
                                                         PROJECT SOLO
                                                      PROJECT SOLO
                                                   PROJECT SOLO
                                              PROJECT SOLO
                                         PROJECT SOLO
                                    PROJECT SOLO
                               PROJECT SOLO
                          PROJECT SOLO
                     PROJECT SOLO
                PROJECT SOLO
           PROJECT SOLO
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   PROJECT SOLO
      PROJECT SOLO
           PROJECT SOLO
                PROJECT SOLO
                     PROJECT SOLO
                          PROJECT SOLO
                               PROJECT SOLO
                                    PROJECT SOLO

HOW'S THAT FOR 'SINING' YOUR NAME!!!!!!!!!!!!

---OR PERHAPS YOU WOULD RATHER BE A 'COSINER'--
                                                           PROJECT SOLO
                                                           PROJECT SOLO
                                                        PROJECT SOLO
                                                     PROJECT SOLO
                                                  PROJECT SOLO
                                               PROJECT SOLO
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              PROJECT SOLO
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                        PROJECT SOLO
                             PROJECT SOLO
                                  PROJECT SOLO
                                       PROJECT SOLO
                                            PROJECT SOLO
                                             PROJECT SOLO

SO LONG--YOU OLD CIRCULAR FUNCTION!!!!!
BY---ROBERT MALLINGER
```
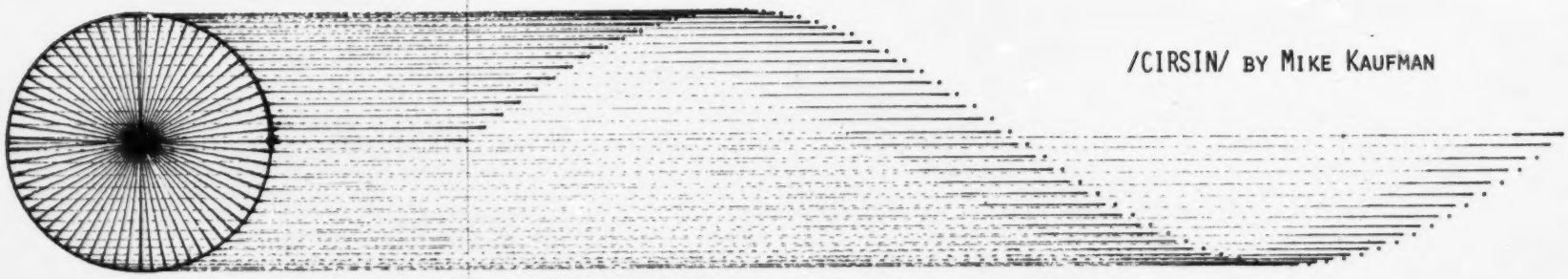
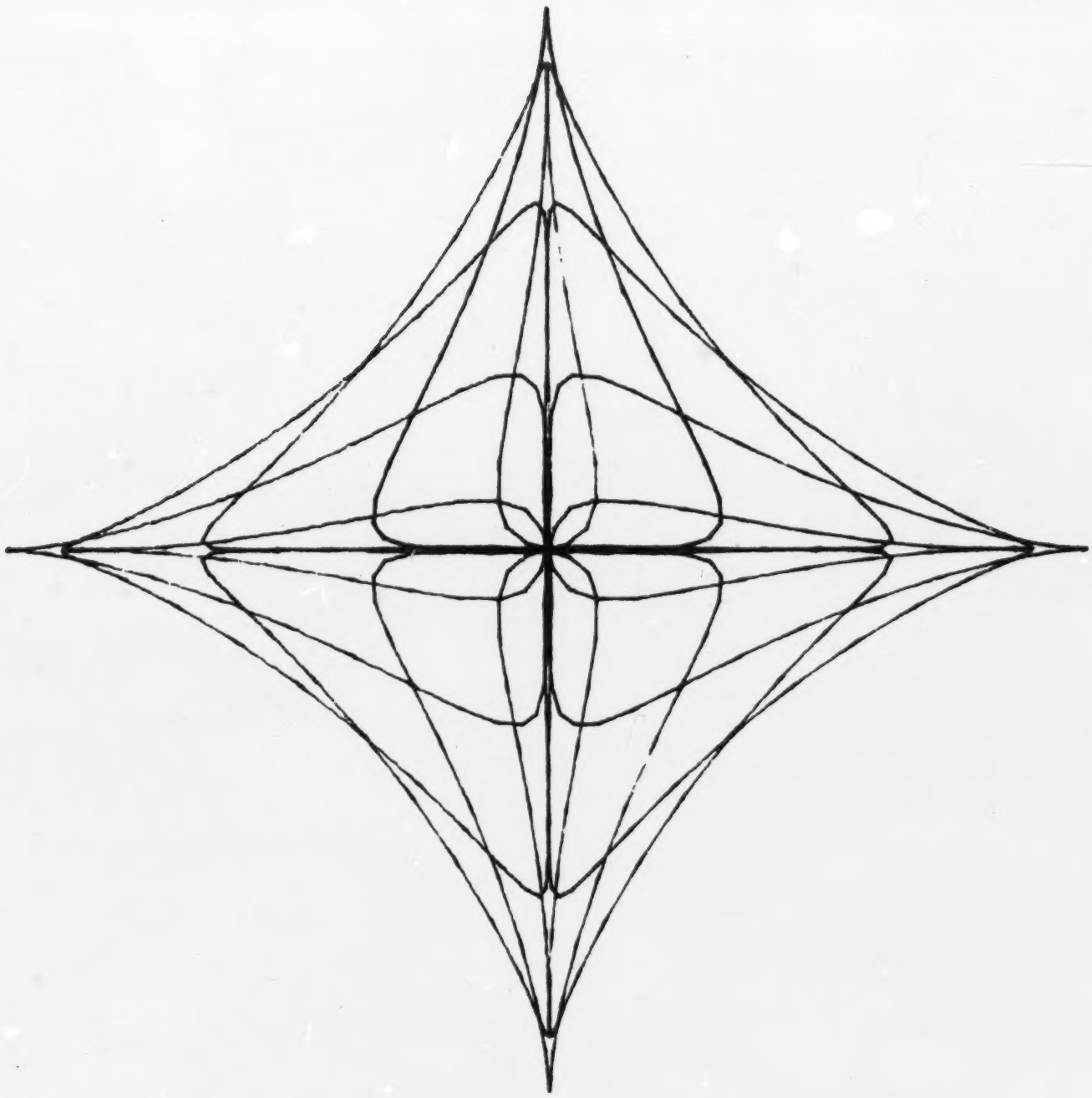



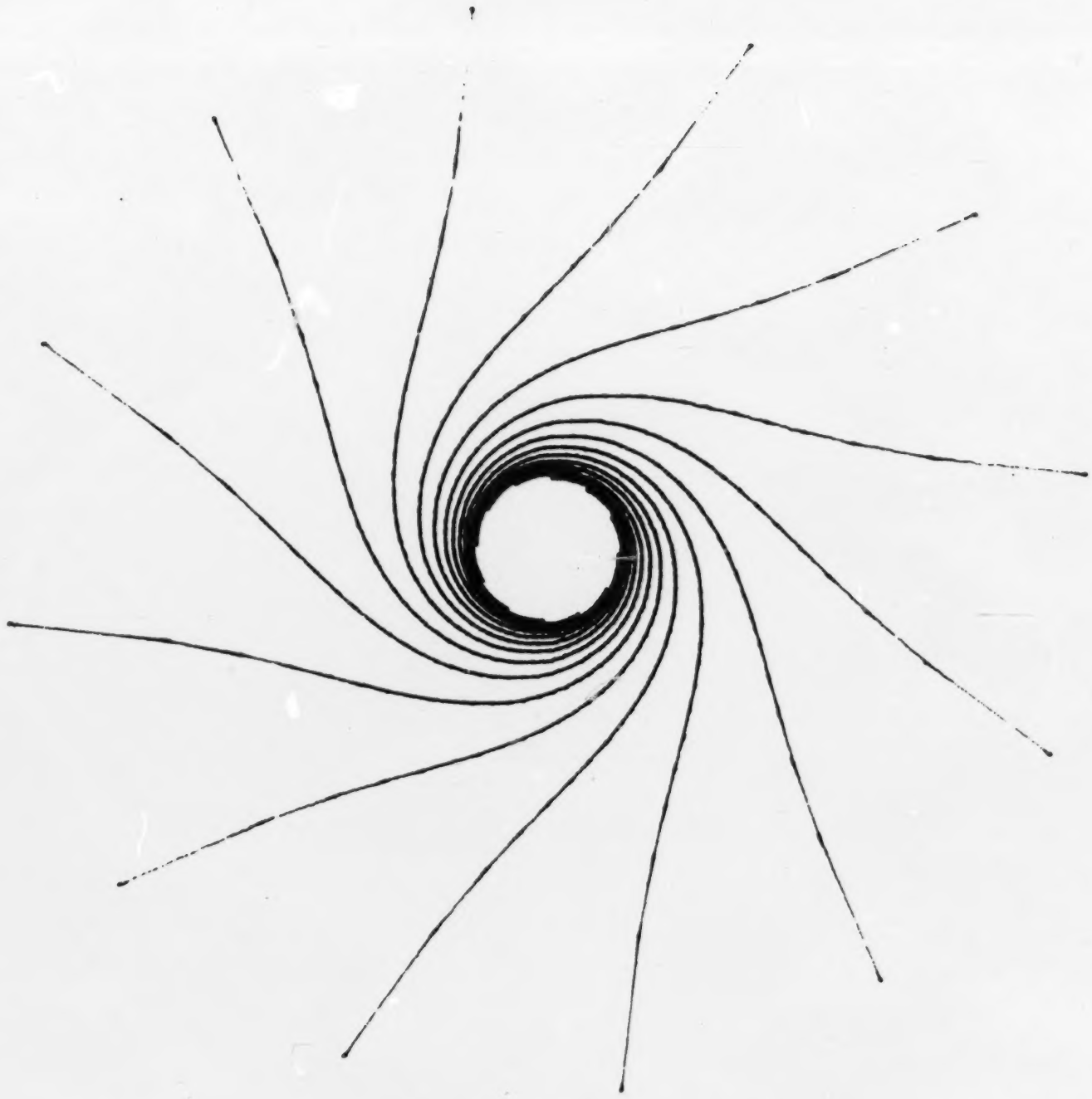
/CIRSIN/ BY MIKE KAUFMAN

```
 APR  1 12:16   /CIRSIN/


10 PR. "PLTL"
20 FOR I=0.0 TO 6.28 STEP .05
30 LET X=COS(I) LET Y=SIN(I)
40 X=1000*X+1500 LET Y=1000*Y+5000
50 PR. INT(.755*X);INT(Y)
60 NEXT I
65 PR."PLTL"
68 PR. INT(.755*(1000*COS(PI/2.)+1500));INT(1000*SIN(PI/2.))+
5000";"
71 PR. INT(.755*(1000*COS(3*PI/2.)+1500));INT(1000*SIN(3*PI/2.))+5000
 8 0 PR. INT(.755*(1000*COS(PI)+1500));INT(1000*SIN(PI))+5000";"
 85 PR. INT(755*COS(PI))+9999;INT(1000*SIN(PI))+5000
86 PR. 3000;2000";"
95 PR. 3000;8000
96 PR. "PLTT"
100 FOR I=0 TO 6.28 STEP .1
110 PR. "PLTL"
120 X=COS(I)*1000+1500 LET Y=SIN(I)*1000+5000
130 PR. 1130;5000";"
133 PR. INT(.755*X);INT(Y)
150 PR. INT(1000*I+3000);INT(Y)
160 NEXT I
165 PR. 0;0";"
166 PR."PLTT"
170 END
```



HYPOCYCLOID
OF FOUR CUSPS
(WITH INTERIOR)
BY
EMMANUEL
SCHRIEBER

```
5 FOR A=0 TO 2*PI STEP PI/6
10 PR. "PLTL"
20 FOR T=0 TO PI STEP PI/32
25 K=SIN(T+A)
30 X=(COS(T))↑3*3000*K
40 Y=(SIN(T))↑3*3000*K
50 PR. INT(X*.755)+5000:INT(Y)+5000
60 NEXT T
70 PR. "PLTT"
75 NEXT A
80 PR. "PLTT"
90 END
```



```
15 FOR A=0 TO 2*PI STEP PI/6
17 PR. "PLTL"
20 FOR T=.01 TO 2*PI STEP PI/32
25 K=T+A
30 R=SQRT(1/T)*1000
40 X=R*COS(K)
45 Y=R*SIN(K)
50 PR. INT(X*.755)+5000:INT(Y)+5000
55 NEXT T
60 PR. "PLTT"
65 NEXT A
68 PR. "PLTT"
70 END
```

LITUUS (ROTATED) BY EMMANUEL SCHRIEBER AND

M.J. VALENTI

EXTRA EXTRA EXTRA EXTRA EXTRA EXTRA

Project Solo

Supplement to Newsletter #15

One of the activities proposed by Project Solo for 1971-72 is to create a syllabus and materials for a high school course in computer science. There are a number of reasons for introducing such a course, especially at the 9th grade level. These reasons include:

1. A reduction in the gap between the subject skills of an 11th or 12th grader, and his computing skills, by giving him early experience with computers.

2. To involve 9th grade students in their education by preparing them to contribute to other classes they will take. They will make this contribution in the role of computer "analyst" for the teacher. The two examples in this supplement illustrate how this can (and has) worked.

3. To introduce the concepts, capabilities and limitations of our "computer age" to most students (possibly opening up careers for some of them).

4. To preview various aspects of a high school education in such a way that students will become interested in working at their education in areas they might normally by-pass. [illegible] module called "Enumeration" which is enclosed illustrates such a computer-oriented approach to a typical topic in mathematics.

Two Examples of Student Contributions to Non-computer Courses

The first example (/FLORA/) illustrates how a student built an interesting training facility for her biology class.

EXAMPLE #1

Identifying Specimens

by Judy Pottmeyer
12th Grade
Fox Chapel High School

This program deals with the problem of identification of a specimen within a given group of organisms. It was an extremely interesting program to work on because it involves research into the specific differences between two or more very similar things.

My purpose in writing /FLORA/ was to apply the computer to the problem of identification. In this program I chose the family BORAGINACEAE (Forget-me-nots) to illustrate this point. The program questions the operator about the characteristics of his plant and deduces the plant he is observing through certain key differences between them. This method of identification is more efficient than the field guide because it tells the observer about the exact differences between his plant and others of the same family. The limitations of this program are: 1. although the family BORAGINACEAE contains 1800 species--tropical trees, herbs, and shrubs, /FLORA/ encompasses only those herbs that live in Northeastern and Northcentral North America as described in Peterson and McKenny's A FIELD GUIDE TO THE WILDFLOWERS, and 2. it does not include the possibilities of mutational effects.

To access the program type:

```
-NBS
>RUN /FLORA/
```

SAMPLE RUN #1

```
THIS IS A KEY TO THE FORGET-ME-NOT FAMILY
IS THE FLOWER ARRANGED IN A ONE SIDED COIL
?YES
ARE THE FLOWERS PARTS MOSTLY IN GROUPS OF 5 WITH 1 STYLE?
?YES

ARE THE LEAVES ALTERNATE?
?YES
ARE THE LEAVES UNDIVIDED?
?YES
GOOD:  THE SPECIMEN YOU HAVE IS IN THE CORRECT FAMILY.
LET'S CONTINUE.
WHAT COLOR IS IT?  TYPE WHITE,YELLOW,RED-PINK OR VIOLET-
BLUE
?VIOLET-BLUE
DOES IT HAVE A BRISTLY STEM?
?NO
ARE THE LEAVES OVAL,SMOOTH,AND STRONGLY VEINED?
?YES
DOES IT LIVE IN BOTTOM LANDS OR RIVER WOODS?
?YES
THE PLANT YOU HAVE IS A MERTENESIA,VIRGINIA COWSLIP OR
COMMON BLUE BELLS-MERTENESIA VIRGINICA!
```

SAMPLE RUN #2

```
THIS IS A KEY TO THE FORGET-ME-NOT FAMILY
IS THE FLOWER ARRANGED IN A ONE SIDED COIL
?YES
ARE THE FLOWERS PARTS MOSTLY IN GROUPS OF 5 WITH 1 STYLE?
?NO
YOU HAVE NOT CHOSEN THE RIGHT FAMILY!  TALK TO YOUR TEACHER
BEFORE PROCEEDING.
FOLLOW LOGOUT PROCEDURES!
```

SAMPLE RUN #3

```
THIS IS A KEY TO THE FORGET-ME-NOT FAMILY
IS THE FLOWER ARRANGED IN A ONE SIDED COIL
?YES
ARE THE FLOWERS PARTS MOSTLY IN GROUPS OF 5 WITH 1 STYLE?
?YES
```

```
ARE THE LEAVES ALTERNATE?
?YES
ARE THE LEAVES UNDIVIDED?
?YES
GOOD:  THE SPECIMEN YOU HAVE IS IN THE CORRECT FAMILY!
WHAT COLOR IS IT?  TYPE WHITE,YELLOW,RED-PINK OR VIOLET-
BLUE
?WHITE
IS THE PLANT ROUGHLY HAIRY WITH THE FLOWERS TUCKED AMONG
THE LEAFY BRACKETS?
?NO
IS THE PLANT SMOOTH AND HAIRY?
?NO
ARE 5 LOBES BRISTLY AND UNEQUAL?
?NO
IS THE FLOWER COVERED WITH A HOARY WHITISH DOWN?
?NO
THE PLANT YOU HAVE IS A FALSE GROMWELL-ONOSMODIUM VIR-
GINIANUM
```

EXAMPLE #2

/QUADRATIC/

by Larry Dunn
10th Grade
Fox Chapel High School

The history of this program is very interesting. A freshman (Mark Pilant) wrote a vocabulary drill for his German class (cf. Newsletter #13). Larry Dunn, a sophomore in that German class found the vocabulary program interesting enough to want to know how it worked. Since the Project Solo philosophy is to make all programs (including CAI) available to students, this was possible. Since our CAI lessons are written in NEWBASIC, Larry learned to "program" in the process of satisfying his curiosity. He then decided to write some programs for the use of his classmates in algebra. The program

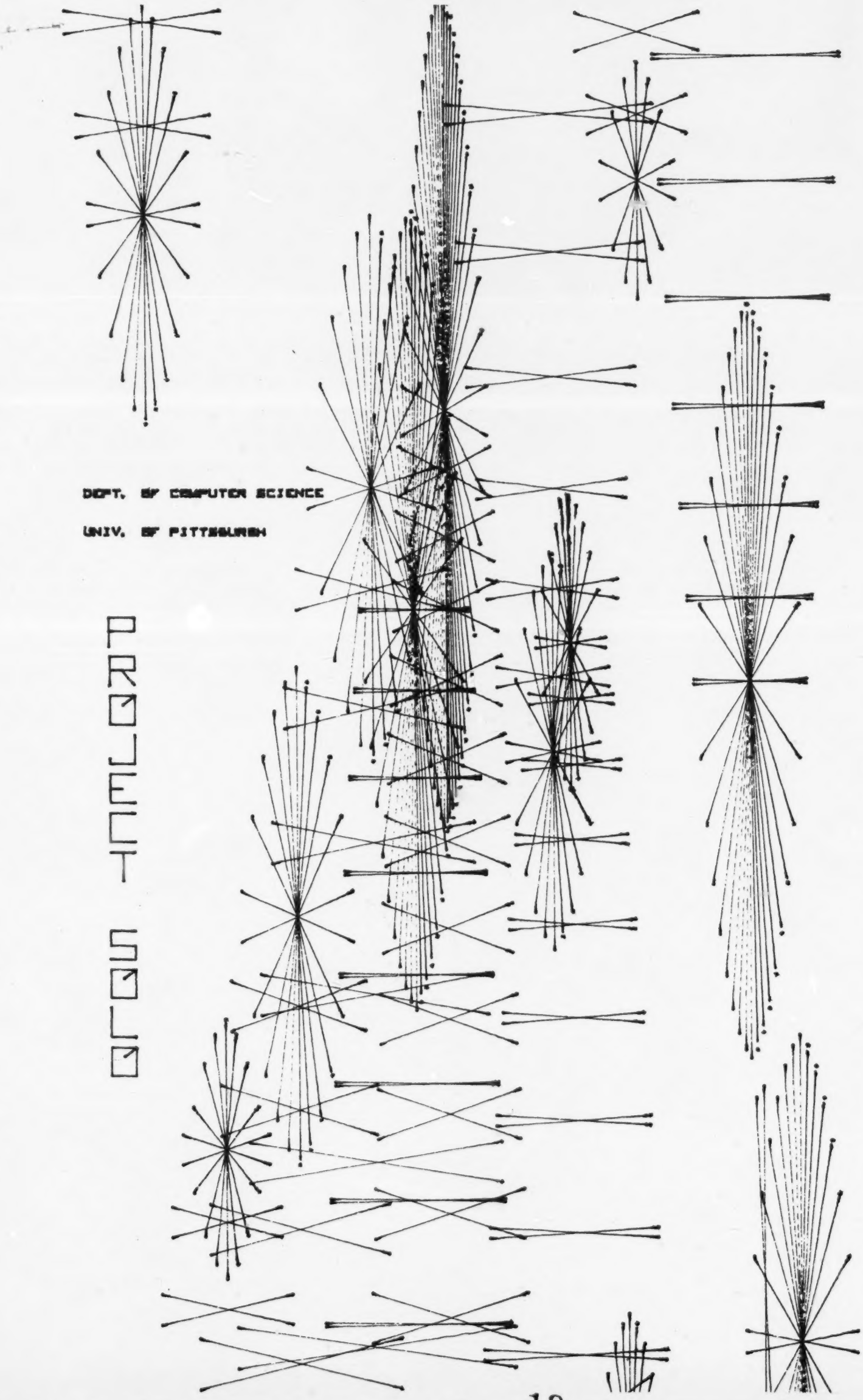
below is one such effort. Here is the important point: Many students have written Quadratic Equation solvers, but under the direction of computer-knowledgeable teachers. In Larry's case, his computer knowledge was the resource his teacher and class used. The teacher supplied the guidance as to what was an interesting problem, and what the mathematical theories needed to solve it were; the student supplied the talent to translate this information into an educational facility.

```
>RUN /QUADRATIC/
TYPE THE NUMBER OF PROBLEMS YOU WISH TO DO.
?3
TYPE THE COEFFICIENT OF A.
?1
TYPE THE COEFFICIENT OF B.
?6
TYPE THE CONSTANT,C.
?3
THE ROOTS OF THE EQUATION ARE (-0.550510257,5.449489743 )
FOR THE EQUATION AX↑2+BX+C=0
TYPE THE COEFFICIENT OF A.
?25
TYPE THE COEFFICIENT OF B.
?16
TYPE THE CONSTANT,C.
?469
THE PROBLEM RESULTS IN COMPLEX ROOTS BECAUSE THE DISCRIMI-
NANT IS LESS THAN 0.
FIRST ROOT IS -0.32+ 4.319444409I
SECOND ROOT IS -0.32- 4.319444409I
FOR THE EQUATION AX↑2+BX+C=0
TYPE THE COEFFICIENT OF A.
?0
THE ROOTS ARE UNDEFINED BECAUSE YOUR DIVISOR IS 0.
THAT'S ALL FOR NOW.  GOOD-BYE BOB.

>EXIT

100 PR."TYPE YOUR NAME PLEASE."
150 INPUT Z$
200 PR."TYPE THE NUMBER OF PROBLEMS YOU WISH TO DO."
250 INPUT L
300 FOR K=1 TO L
350 PR."FOR THE EQUATION AX↑2+BX+C=0 "
400 PR."TYPE THE COEFFICIENT OF A."
450 INPUT A
```

```
475 IF A=0 THEN 1160
500 PR."TYPE THE COEFFICIENT OF B."
550 INPUT B
600 PR."TYPE THE CONSTANT,C."
650 INPUT C
700 LET L=(B*B)-4*A*C
749 IF(B*B)-4*A*C<0 THEN 950
750 LET M=(-B+SORT(L))/(2.*A)
800 LET N+(-B-SORT(L))/(2.*A)
900 GOTO 1100
950 PR."THE PROBLEM RESULTS IN COMPLEX ROOTS "
951 PR."BECAUSE THE DISCRIMINANT IS LESS THAN 0."
952 LET L=-L
953 LET R=(SORT(L))/(2.*A)
954 LET R1=(-B)/(2.*A)
955 PR."FIRST ROOT IS ":R1:"+":R:"I"
956 PR."SECOND ROOT IS ":R1:"-":R:"I"
1050 GOTO 1175
1100 PR."THE ROOTS OF THE EQUATION ARE (":M:",":N:" )"
1150 GOTO 1175
1160 PR."THE ROOTS ARE UNDEFINED BECAUSE YOUR DIVISOR IS 0"

1175 NEXT K
1200 PR."THAT'S ALL FOR NOW.  GOOD-BYE ":Z$:"."
1250 END
```

DEPT. OF COMPUTER SCIENCE

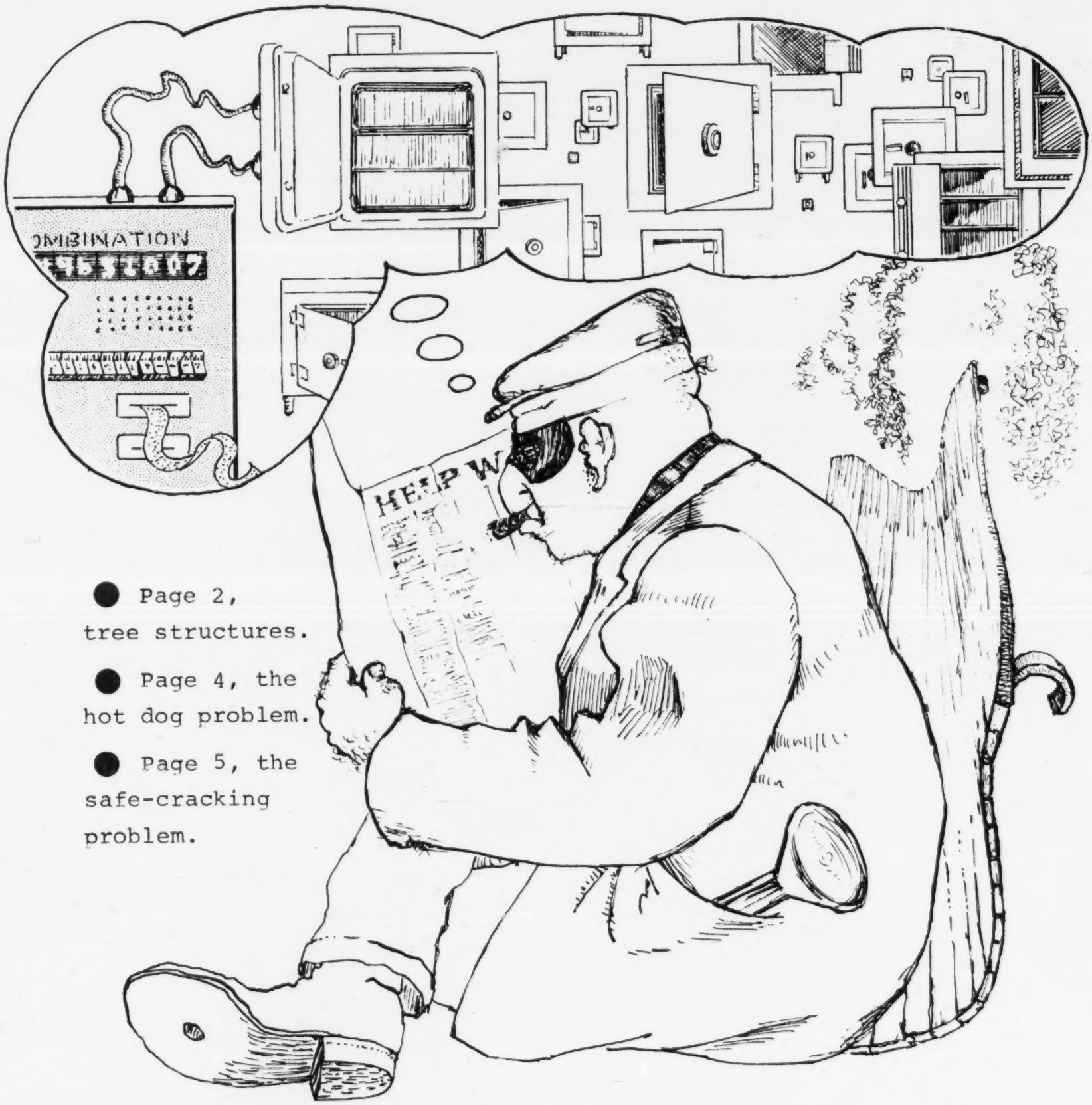
UNIV. OF PITTSBURGH



PROJECT ATLAS

```
7 ØPEN // FØR ØUTPUT AS 3
10 K=0
12 B=NUM(100)
14 IF B<25 GØTØ 12
16 X=NUM(9999)
18 Y=NUM(8000)
19 IF Y<1000 GØTØ 18
20 Z=NUM(9999)
22 M=INT((X+Z)/2)
24 N=INT(ABS(X-Z)/2)
26 IF ABS(X-Z)<1000 ØR ABS(X-Z)>5000 GØTØ 16
30 PRINT ØN 3: "PLTP"
32 PRINT ØN 3: X;Y
34 PRINT ØN 3: "PLTL"
36 PRINT ØN 3: Z;Y
38 PRINT ØN 3: "PLTP"
40 FØR I=B BY B
41 IF I>M ØR Z-I<0 ØR X-I<0 ØR Y-I<0 ØR Z+I>9999 ØR X+I>9999 ØR Y+I>99
99 GØTØ 62
42 IF X<Z, X=X+I ELSE X=X-I
43 IF X<Z, Z=Z-I ELSE Z=Z+I
44 PRINT ØN 3: X;Y+I
45 PRINT ØN 3: "PLTL"
46 PRINT ØN 3: Z;Y-I
47 PRINT ØN 3: "PLTP"
48 PRINT ØN 3: Z;Y+I
49 PRINT ØN 3: "PLTL"
50 PRINT ØN 3: X;Y-I
51 PRINT ØN 3: "PLTP"
52 NEXT I
62 L=L+1, [IF L>3, GØTØ 66]
63 TYPE "ØNE DØNE"
64 GØTØ 12
66 PRINT ØN 3: "PLTT"
67 K=K+1, L=0, [IF K>3, GØTØ 76]
74 GØTØ 12
76 CLØSE 3
78 END
>RUN
ØPENING FILE 3, SYMBØLIC ØUTPUT, NAME: /STARS/
NEW FILE?
ØNE DØNE
ØNE DØNE
ØNE DØNE
ØNE DØNE
ØNE DØNE
ØNE DØNE
ØNE DØNE
ØNE DØNE
ØNE DØNE
ØNE DØNE
ØNE DØNE
ØNE DØNE
ØNE DØNE

>-CØPY
FILE NAME:/STARS/
 TØ: TPT
PLTP
 7047      3483
  ....... etc. .......
```

Listing of a plotter program written by Chris Van Sickle (Grade 8). Part of the pattern produced on the plotter is reproduced on the cover.



- Page 2, tree structures.
- Page 4, the hot dog problem.
- Page 5, the safe-cracking problem.

ENUMERATION

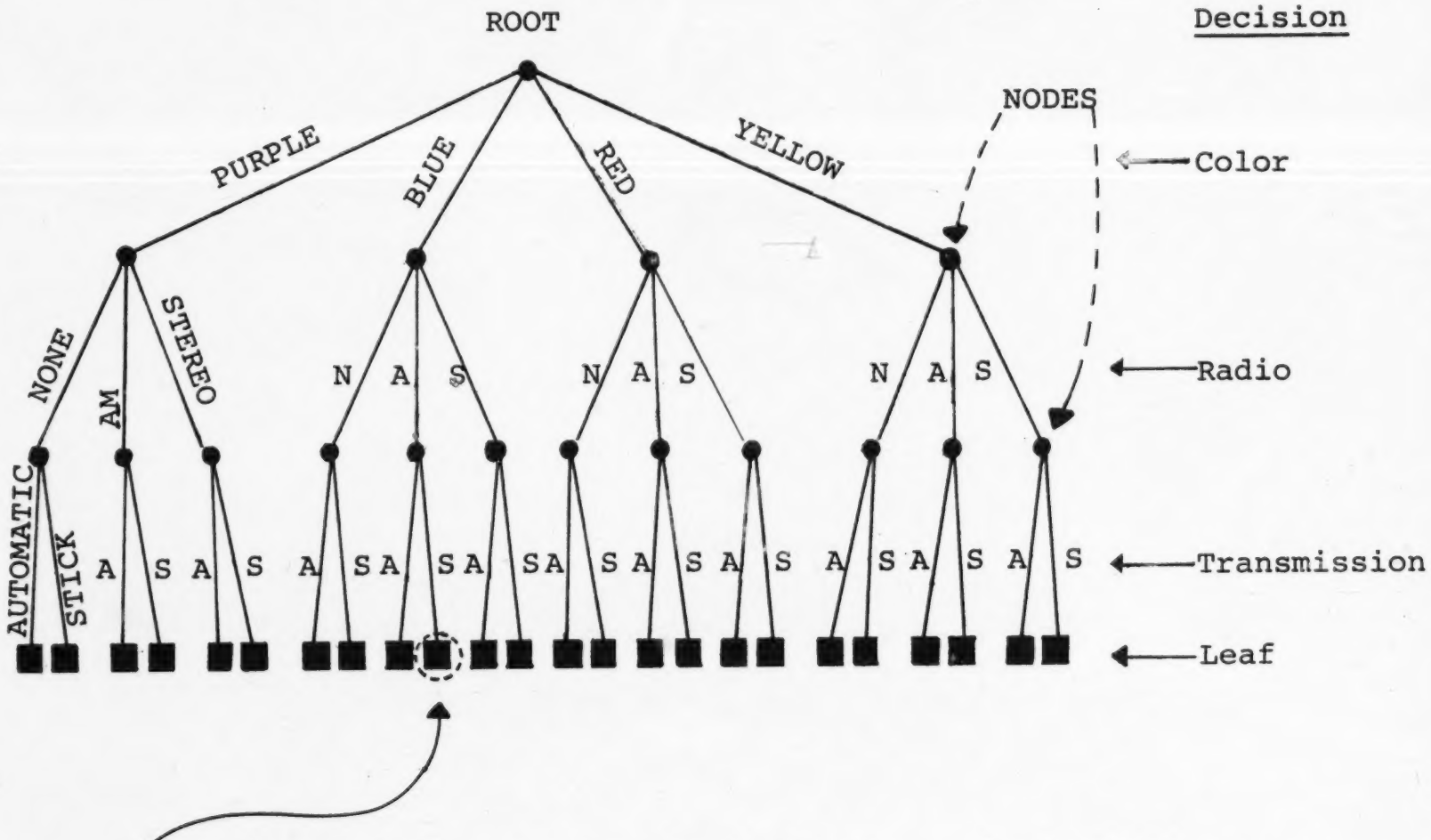
PROJECT SOLO/Computer Science Dept./University of Pittsburgh 15213

ENUMERATION

Decisions, Decisions

You finally decide to get the car of your dreams--a brand new Toyo-Beetle. This sounds simple enough, but then you find out about options: Color, Radio, Transmission, etc. How many choices are there?

A good way to analyze such problems is to draw a picture showing the decisions as branches in what is usually called a decision Tree.



Each "square" is called a terminal node or leaf of the tree. This leaf is at the end of a path which corresponds to the choice of a Blue car with AM radio and stick shift.

It is easy to see that there are 4*3*2 = 24 leaves; therefore, there are 24 choices of car with the variables shown. The problem of listing all possible choices is sometimes called the problem of ENUMERATION.

Writing a Program for Enumeration

Use of nested FOR loops is a good way to systematically generate all the possible ways in which various choices of objects can be combined.

Example 1: Write a program to generate all two digit numbers N that are even and lie in the range $10 \leq N \leq 28$.

Solution: We can use one FOR loop to control the first digit of N so that it is 1 or 2, and a second FOR loop to control the second digit so that it is 0,2,4,6, or 8.

```
10 FØR J=1 TØ 2
20 FØR K=0 TØ 8 BY 2
30 PRINT J;K
40 NEXT K
50 NEXT J
```

```
>RUN
 1 0
 1 2
 1 4
 1 6
 1 8
 2 0
 2 2
 2 4
 2 6
 2 8
```

Short form solution of Example 1:

```
>[PR. J;K FØR K=0 TØ 8 BY 2]FØR J=1 TØ 2

 1 0
 1 2
 1 4
 1 6
 1 8
 2 0
 2 2
 2 4
 2 6
 2 8
```

Example 2: Write all the names that use John, Henry, and Bill as first names, and Smith and Jones as last names.

```
>10 LET A$(1)="J0HN" LET A$(2)="HENRY" LET A$(3)="BILL"
>20 LET B$(1)="SMITH" LET B$(2)="J0NES"
>30 [PR. A$(J)+" "+B$(K) F0R K=1 T0 2]F0R J=1 T0 3
>RUN

J0HN SMITH
J0HN J0NES
HENRY SMITH
HENRY J0NES
BILL SMITH
BILL J0NES
```

Assignment Problem 1:

Write a program that enumerates all the ways you can buy a hot dog at a stand that allows for bun, hot dog, heavy mustard, light mustard, and relish. (Hint: You really have three choices for mustard (heavy, light, or none), and two choices for all the other ingredients (yes or no)). A sample run might look like this:

SELECTI0N #				
1	BUN	D0G	MUSTARD	RELISH
2	BUN	D0G	MUSTARD	N0 RELISH
3	BUN	D0G	1/2 MUSTARD	RELISH
4	BUN	D0G	1/2 MUSTARD	N0 RELISH
5	BUN	D0G	N0 MUSTARD	RELISH
6	BUN	D0G	N0 MUSTARD	N0 RELISH
7	BUN	N0 D0G	MUSTARD	RELISH
8	BUN	N0 D0G	MUSTARD	N0 RELISH
9	BUN	N0 D0G	1/2 MUSTARD	RELISH
10	BUN	N0 D0G	1/2 MUSTARD	N0 RELISH
11	BUN	N0 D0G	N0 MUSTARD	RELISH
12	BUN	N0 D0G	N0 MUSTARD	N0 RELISH
13	N0 BUN	D0G	MUSTARD	RELISH
14	N0 BUN	D0G	MUSTARD	N0 RELISH
15	N0 BUN	D0G	1/2 MUSTARD	RELISH
16	N0 BUN	D0G	1/2 MUSTARD	N0 RELISH
17	N0 BUN	D0G	N0 MUSTARD	RELISH
18	N0 BUN	D0G	N0 MUSTARD	N0 RELISH
19	N0 BUN	N0 D0G	MUSTARD	RELISH
20	N0 BUN	N0 D0G	MUSTARD	N0 RELISH
21	N0 BUN	N0 D0G	1/2 MUSTARD	RELISH
22	N0 BUN	N0 D0G	1/2 MUSTARD	N0 RELISH
23	N0 BUN	N0 D0G	N0 MUSTARD	RELISH
24	N0 BUN	N0 D0G	N0 MUSTARD	N0 RELISH

(#24 is the Weight-Watchers Special sometimes known as the "Null" dog.)

Assignment Problem 2: (Optional--For Rich Students Only)

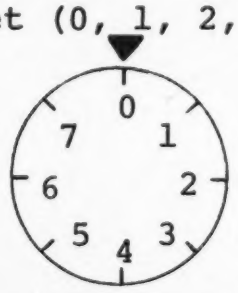
A real company in Pittsburgh advertises hot dogs on which you can get mustard, relish, onions, pickles, mayonnaise, ketchup, chili, kraut, cheese, tabasco, spaghetti, and tartar sauce. The sign in the window says that there are 8,826 ways you can order a hot dog at this shop. Is this correct????

(Assume YES or NO decisions for each ingredient, including the bun and hot dog.)

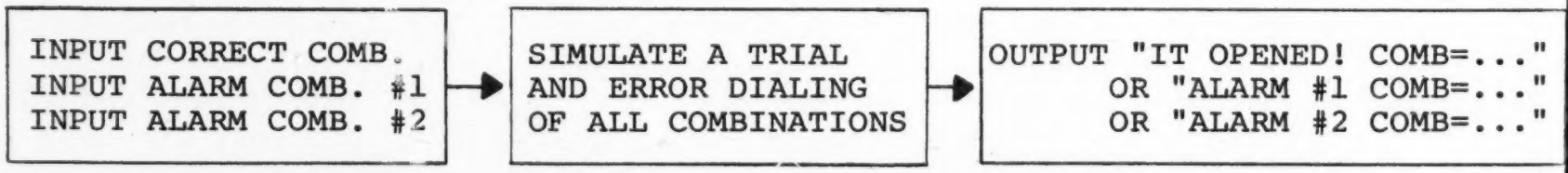
WARNING: Don't use the computer for this problem until making a $ estimate of the run. Assume that you print one line for each hot-dog combo, with 60 characters per line, at a speed of 10 characters per second, at a cost of $10.00 per hour, and that you will volunteer to pay one half the total cost.

Assignment Problem 3:

Write a program to simulate someone trying to open a safe by trial and error. The safe uses a 3-number combination of the form "RIGHT A, LEFT B, RIGHT C" where A, B, and C are integers from the set (0, 1, 2, 3, 4, 5, 6, 7).



The safe has been "rigged" to sound an alarm if either one of two false combinations are dialed.


INPUT CORRECT COMB.
INPUT ALARM COMB. #1
INPUT ALARM COMB. #2
SIMULATE A TRIAL AND ERROR DIALING OF ALL COMBINATIONS
OUTPUT "IT OPENED! COMB=..."
OR "ALARM #1 COMB=..."
OR "ALARM #2 COMB=..."

Extra (Two Student Contest): Student #1 appends the simulation program to the input/output programs of student #2 to see if he can open the safe. (The students will have to agree on use of variable names etc.)

Preview Section--later modules will give more advanced techniques using "Trees" for solving enumeration problems. Here are some of these problems which you might like to try now.

1. Given a positive integer k, how many different sequences of numbers $w_1, w_2, \ldots, w_m$ are there such that

   i) $w_1+w_2+\ldots+w_m = k$
   ii) each w_i is a positive integer
   iii) for $1 \leq i \leq m-1$, $w_i \leq w_{i+1}$.

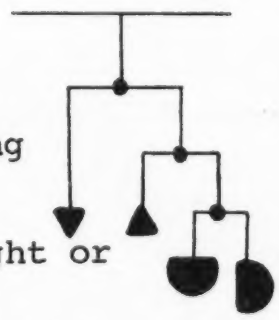
   (This is called the partitioning problem for the integer k.)

2. Given a set of coin denominations $d_1, d_2, \ldots, d_n$ (i.e. a monetary system, such as 1, 5, 10, 25 for U.S. coins), and a positive sum s, how many different coin sets have value s?

3. (Game of 3's). Consider the following game description:
   i) there are two opponents
   ii) each player alternately selects digits from the set (1,2,3)
   iii) each selection (except of course the first) may not repeat the immediately preceding selection
   iv) the game ends when
      a) the sum of digits selected equals 8, in which case the player selecting the last digit is winner, or
      b) a player is forced to make the sum greater than 8, in which case he is the loser.

   How many different game sequences are possible?

4. (Enumeration of binary trees) Mobiles, the hanging art objects, are formed by connecting a set of arms, weights, and strings. Each mobile obeys the following general organization:



   i) each arm has tied to its ends either a weight or or another arm (one only)
   ii) all arms but one (the top one) are each tied to the end of another arm (one only).

Given n weights, how many different ways are there of constructing a mobile from these weights and an ample supply of arms and string? (The weights can be adjusted to any value required for balance.) The problem is to count (enumerate) different arrangements, not to calculate balance.)

5. Given a set of m males and f females, how many different sets of family relationships are possible, assuming:
   i) each individual has at most one spouse, of opposite sex;
   ii) only people with spouses have children;
   iii) individuals may not have as their spouses:
      a) any ancestor (parent, parent of parent, etc.)
      b) a sibling (brother or sister).

6. Given a set of n points in the plane, how many different polygons can be found by connecting them in a (cyclical) sequence? (Note: a connection sequence forms a polygon if the connection lines intersect only at their end points.)

7. (n- queens problem) How many ways can n queens be placed on an nxn chess board so that no queen attacks another?

8. (knights tour) From how many squares of the chess board can a knight traverse the entire board landing on each square just once?

Other Advanced Problems include:

Tower of Hanoi puzzle
Traveling salesman problem
Four color problem
Topological sort of directed graph
Tournament matchings
Enumerations of sentences of length k from BNF grammar